

Elevation Uncertainty in Sea-Level Rise Assessments: How Much Land is Really at Risk?

Dean B. Gesch (gesch@usgs.gov)

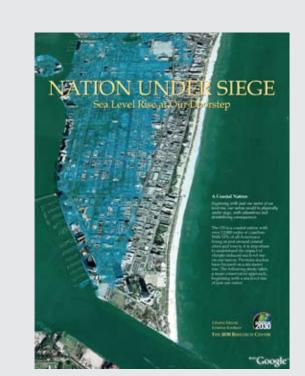
U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD 57198, USA.

Introduction / Background

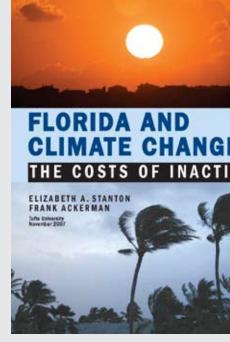
One of the most critical scientific issues in the coastal environment today is determining the physical response of coastlines to predicted sea-level rise. However, as with many natural hazards, communicating the risks associated with sea-level rise remains a challenge. Part of the challenge may stem from the fact that sea-level rise is a long-term, slowly varying process, and the consequences are often not immediately observable.

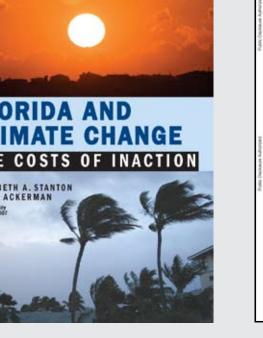
Topography is a key parameter that influences many of the physical processes involved in coastal change; therefore, up-to-date, high-resolution, high-accuracy elevation data are required to model the coastal environment. Elevation is only one of a number of interrelated factors that determine the vulnerability of lands to the effects of sea-level rise. For some areas, simple *inundation* will be the primary response to SLR – in these areas elevation is the most important factor in assessing potential impacts. The accuracy and resolution with which coastal elevations have been mapped directly affect the reliability and usefulness of sea-level rise impact assessments that rely upon elevation as the foremost geophysical characteristic for determining vulnerability.

Maps depicting coastal areas subject to potential inundation or other adverse effects of sea-level rise have great appeal to planners and land managers who are charged with adapting to or reducing the risks. Likewise, sea-level rise assessments often include statistical summaries of population, infrastructure, and economic activity in the mapped impact zone because this information is critical for the mitigation efforts. Many studies have necessarily used elevation data to delineate potential impact zones and quantify effects.

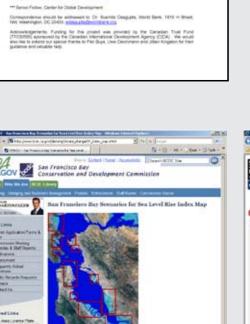




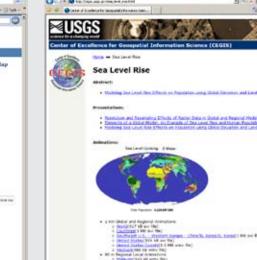












Sea Level Rise on Transportation

Maps and visualizations, including computer simulations, of the spatial extent of potential sea-level rise are a common method of attempting to communicate the risk to coastal areas. Often the maps are included in assessment reports issued by various nongovernmental organizations, universities, state and local agencies, and other private groups. Numerous Web sites provide both static and dynamic displays of rising sea level and its impact on the land for scientific and general public audiences. Few of the papers, reports, maps, or Web sites mention anything about the quality of the input data. None address the inherent vertical uncertainty of the elevation data quantitatively, although some offer general caveats about limitations of the data and that the maps are for illustration only and should not be used for detailed planning.

A variety of elevation datasets has been used in previous studies to quantify the amount of land and affected population subject to potential inundation from sea-level rise. The scale, or horizontal resolution, of the elevation data ranges from a coarse resolution of about 1 kilometer for global and regional assessments to a fine resolution of a few meters for local studies.

In the last several years, vast amounts of high quality elevation data derived from light detection and ranging (lidar) have become available, and they are highly suitable for detailed study of the physical processes related to sea-level rise. The significantly improved spatial resolution and vertical accuracy of lidar-derived elevation data provide clear advantages for use in delineating lands subject to a given sea-level rise scenario.

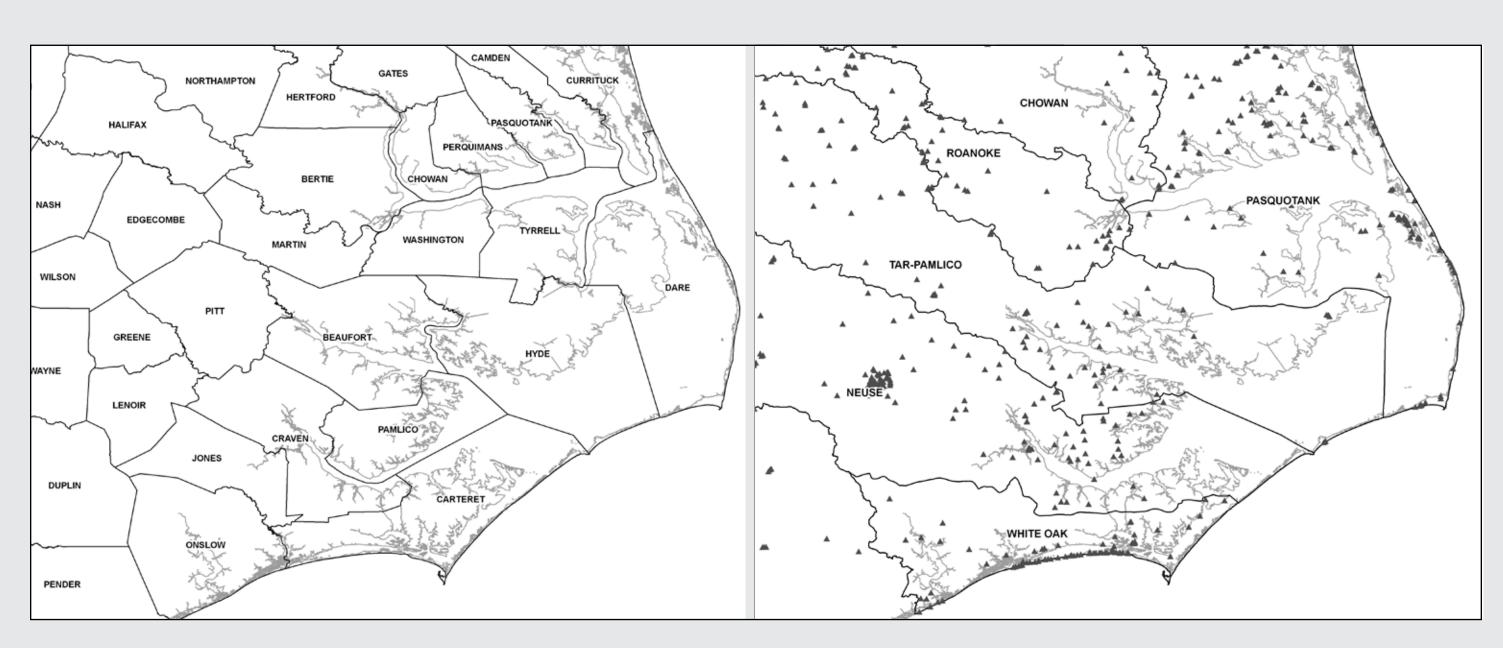
An analysis of four different elevation datasets, including lidar, that have been commonly used for mapping vulnerable coastal lands demonstrates that vertical uncertainty (elevation error) must be considered quantitatively to derive reliable estimates of land areas subject to potential inundation. Maps that include a spatial representation of the uncertainty associated with a given sea-level rise projected onto the land can then be produced. The following analysis includes a quantification of the vertical accuracy of the various DEM datasets that have been used to model potential sea-level rise impacts and a demonstration of how the improved quality of lidar data leads to more precise delineation of vulnerable coastal lands.

Data, Study Area, Methods

Elevation data from the following sources were processed and analyzed for coastal North

- Carolina, including the Outer Banks and the Albemarle-Pamlico Sound estuarine system: USGS National Elevation Dataset (NED) 1/9-arc-second layer (derived from lidar)
- USGS NED 1-arc-second layer (derived from topographic maps) Shuttle Radar Topography Mission (SRTM) 3-arc-second data
- USGS GTOP030 30-arc-second global elevation model

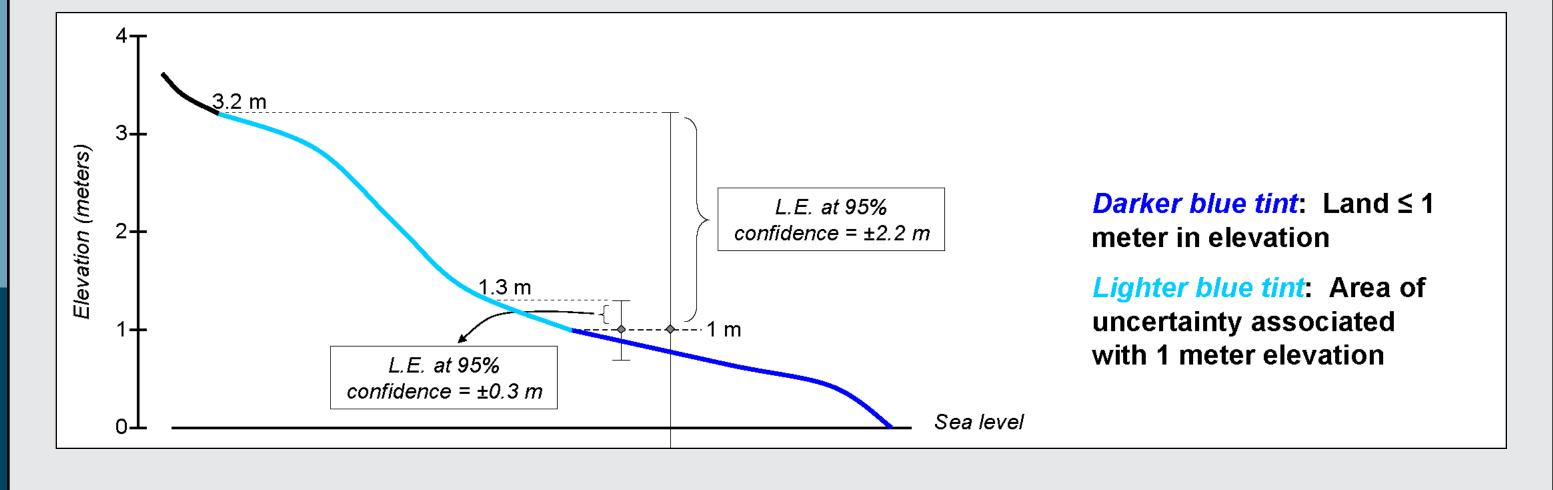
The study area is contained within the Pasquotank, Chowan, Roanoke, Tar-Pamlico, Neuse, and White Oak river basins. The availability of high quality lidar data over a broad, diverse coastal area provides an excellent opportunity to examine how the resolution and accuracy of elevation datasets affect sea-level rise analysis.



To properly portray the uncertainty in potential inundation levels delineated from elevation data, the absolute vertical accuracy of the data must be known. The accuracies of the 1-arc-second NED, SRTM, and GTOPO30 data, expressed as the root mean square error (RMSE), were calculated by comparison with an independent reference set of highaccuracy geodetic control points from the National Geodetic Survey (489 points in the study area). For the 1/9-arc-second NED from the lidar, the vertical accuracy is an average of the RMSE for each of the 21 coastal counties in the study area as reported by the North Carolina Floodplain Mapping Program, the distributor of the lidar data. In addition to the RMSE for each elevation dataset, the linear error (L.E.) with a 95% confidence level, which is the metric used by the National Standard for Spatial Data Accuracy (NSSDA), was also calculated with the following equation: L.E. at 95% confidence = 1.96 * RMSE

Elevation data	Grid spacing	Approximate resolution	Absolute vertical accuracy over NC study area	
			RMSE (meters)	L.E. at 95% confidence (meters)
GTOPO30	30 arc-seconds	1 kilometer	3.83	± 7.51
SRTM	3 arc-seconds	90 meters	3.13	± 6.13
NED (map source)	1 arc-second	30 meters	1.27	± 2.21
NED (lidar source)	1/9 arc-second	3 meters	0.14	± 0.27

The uncertainty of elevation data affects the delineation of coastal elevation zones. In this example, a hypothetical sea-level rise of 1 meter is to be mapped onto the land surface, and two elevation datasets are available for map production. On a topographic profile diagram, two elevation datasets with differing vertical accuracies can be shown with error bars around the 1-meter elevation. One dataset has an L.E. of ± 0.3 meters at a 95% confidence level, while the other has an L.E. of ±2.2 meters at a 95% confidence level. By adding the L.E. to the projected 1-meter sea-level rise, more area is added to the inundation zone delineation, and this additional area is a spatial representation of the uncertainty. The additional area is interpreted as the region in which the 1-meter elevation may actually fall, given the statistical uncertainty of the original elevation measurements.



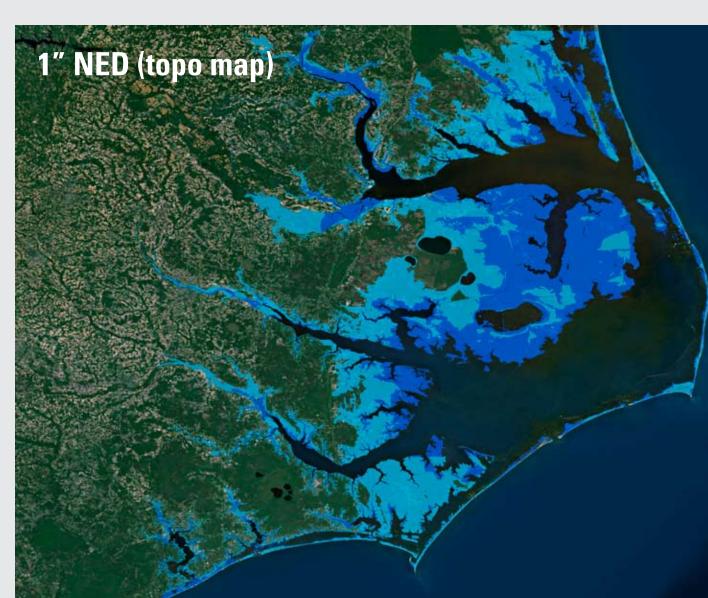
Results

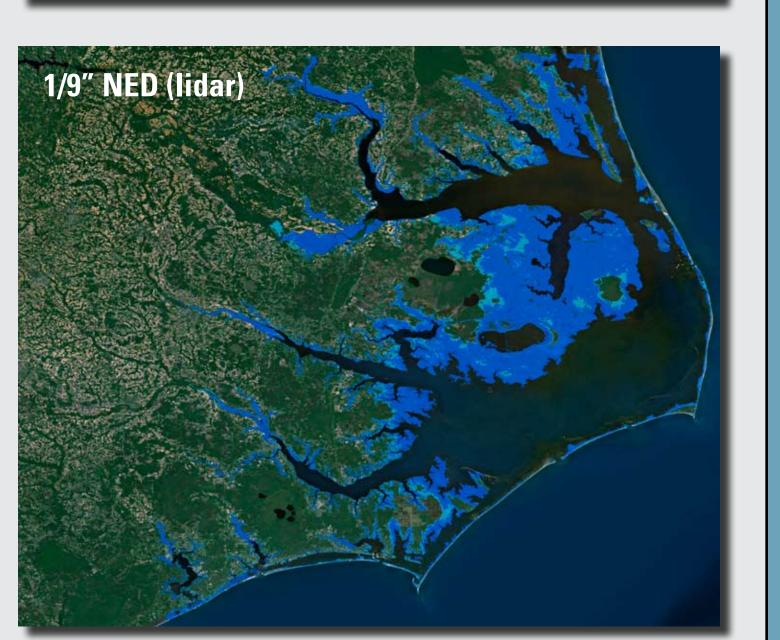
For the examples in this study, a 1-meter sea-level rise was used to produce maps of potential inundation areas. Calculation of the potential inundation zones was accomplished with an approach in which raster elevation data are "flooded" by identifying the land cells that have an elevation at or below a given sea-level rise scenario and are connected hydrologically to the ocean.

For each of the four elevation datasets, maps of potential inundation zones given a 1-meter sea-level rise were produced by extracting the area from the DEM at or below that elevation and overlaying it on a background image. These areas are depicted in the darker blue tint on the maps below. For each dataset, additional areas were delineated to show a spatial representation of the uncertainty of the projected inundation area. This delineation was accomplished by adding the L.E. at 95% confidence to the 1-meter sea-level increase and extracting the area from the DEM at or below that elevation using the same flooding algorithm as before. These additional areas are shown in the lighter blue tint on the maps. The delineation that includes the elevation uncertainty (lighter blue tint) will always cover more area than the delineation without (darker blue tint), but the areas are coincident up to the 1-meter contour.







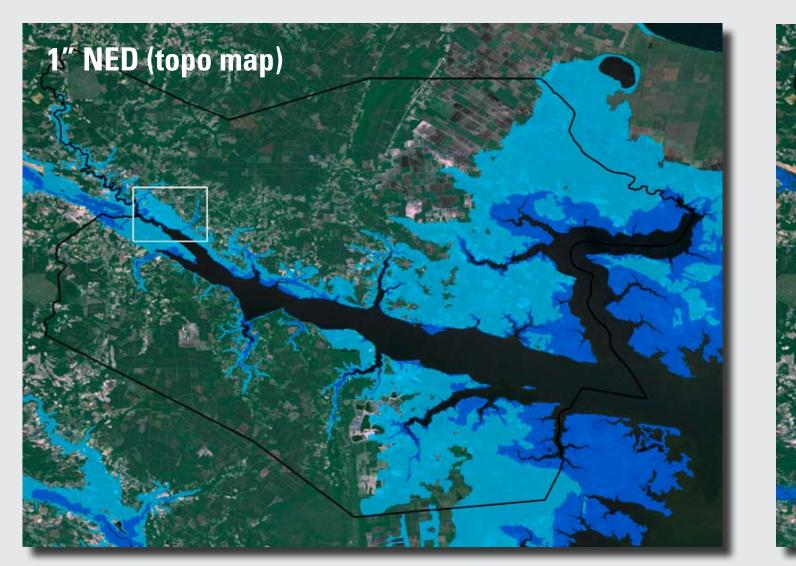


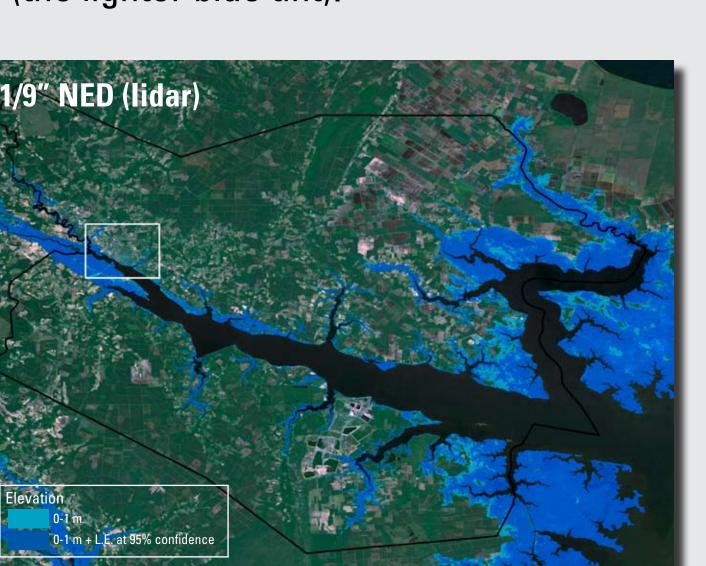
In addition to maps of vulnerable lands, most studies examining the impacts of sea-level rise also report the total area of the inundation zone. The area of inundation from a 1-meter sea-level rise was calculated from the four elevation datasets, including error effects. As the vertical accuracy of the elevation model improves, the difference between the area below 1 meter in elevation and the area below 1 meter plus the uncertainty (L.E. at 95% confidence) decreases. On the vulnerability maps, this decrease in uncertainty is reflected in the decreased area of the lighter blue tint. If the input elevation data had no vertical uncertainty, there would be no lighter blue tint on the map. In reality there will always be uncertainty associated with the elevation data, but these results demonstrate that the use of highly accurate lidar data improves the delineation of inundation zone. In this case, the lidar-based delineation is greater by only 14% (at the 95% confidence level) when the accuracy of the elevation model is considered. For the delineations from the GTOPO30, SRTM, and 1-arc-second NED data, the inundated area more than doubles when the elevation uncertainty is considered, which calls into question the reliability of any conclusions drawn from delineations based on those datasets.

Elevation data	Area ≤ 1 meter in elevation (sq. kilometers)	Area ≤ 1 meter in elevation at 95% confidence (sq. kilometers)	Percent increase in vulnerable area when elevation uncertainty is included
GTOPO30	6,205.3	14,986.5	142%
SRTM	469.6	6,859.7	1,361%
NED (map source)	4,014.0	8,577.9	114%
NED (lidar source)	4,195.3	4,783.2	14%

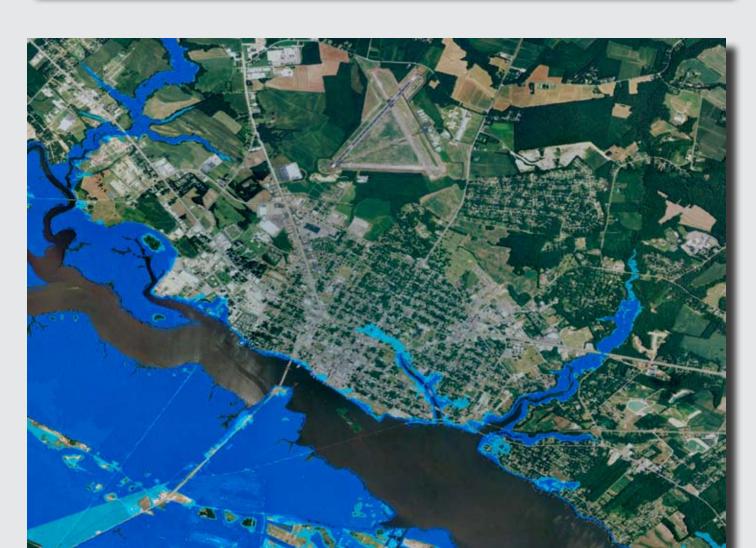
Discussion / Conclusions

Maps of some subsets of the study area in Beaufort County were developed at a larger scale to emphasize the difference between two of the elevation sources, namely the 1-arcsecond NED (derived from topographic maps) versus the 1/9-arc-second NED (derived from lidar). The delineations differ not only because of the increased spatial resolution of the lidar data but also because of the better vertical accuracy of the lidar, which is reflected in the much smaller area of uncertainty (the lighter blue tint).









The level of uncertainty inherent in the topographic map source for the 1-arc-second NED, even without any additional error contributed by the elevation model generation process, is nearly the amount of sea-level rise (1 meter) that is modeled in many studies. Lidar elevation models with accuracies quantified in the 25 centimeter range (at 95% confidence) are much more appropriate for identification of areas vulnerable to sea-level rise in the meter range.

The overall findings from this study demonstrate that:

factors contribute to future shoreline position.

- The quality and characteristics of elevation data used for sea-level rise impact assessments greatly affect the reliability of the results.
- The improved vertical accuracy of lidar elevation data, as well as its increased spatial detail, provides enhanced topographic information that is advantageous to sea-level rise impact studies – representing a significant upgrade over datasets previously used in global and regional assessments.
- Spatially explicit vulnerability maps can be produced from highly detailed and accurate lidar elevation data.
- Statistical summaries of impacted population and other socioeconomic variables within the mapped inundation zone also benefit by incorporating the elevation uncertainty
- The reliability of estimates of land and population at risk derived from global datasets is questionable because of the inherent vertical uncertainty of the elevation data. Vertical increments in sea-level rise vulnerability studies should match the elevation
- data accuracy. • The landward edge of the inundation zone is <u>not</u> the future shoreline – many other

References

Gesch, D.B., 2007, Chapter 4 – The National Elevation Dataset, in Maune, D. (ed.), Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, p. 99-118.

Gesch, D.B., 2009, Analysis of lidar elevation data for improved identification and delineation of lands vulnerable to sea level rise: Journal of Coastal Research (in press).

Poulter, B., and Halpin, P.N., 2007, Raster modelling of coastal flooding from sea-level rise: International Journal of Geographical Information Science, v. 22, no. 2, p. 167-182.

U.S. Department of the Interior U.S. Geological Survey